

LAGRANGE INTERPOLATION

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Example

The upward velocity of a rocket is given as a function of time in Table 1. Find the velocity at $t=16$ seconds using the Lagrangian method for linear interpolation.

Table Velocity as a function of time

t (s)	$v(t)$ (m/s)
0	0
10	227.04
15	362.78
20	517.35
22.5	602.97
30	901.67

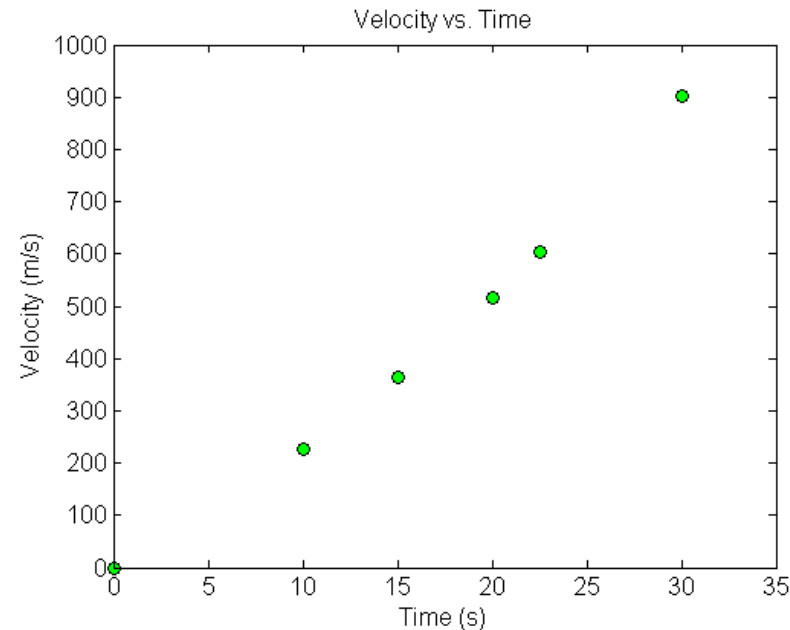


Figure. Velocity vs. time data
for the rocket example

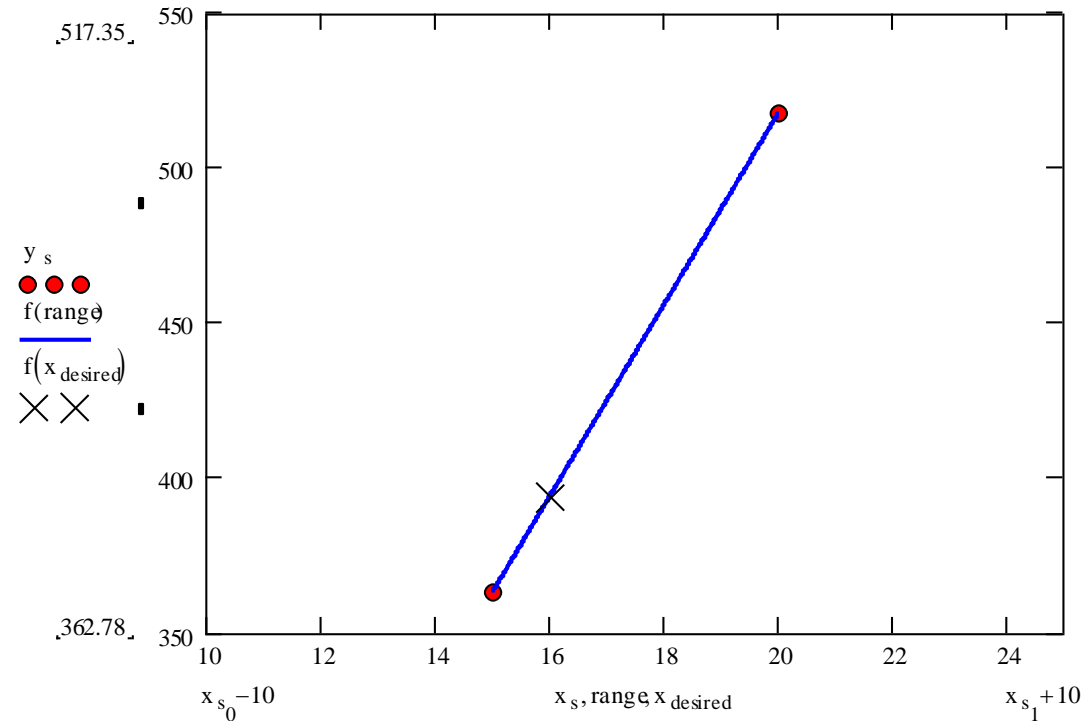
Linear Interpolation

$$v(t) = \sum_{i=0}^1 L_i(t)v(t_i)$$

$$= L_0(t)v(t_0) + L_1(t)v(t_1)$$

$$t_0 = 15, v(t_0) = 362.78$$

$$t_1 = 20, v(t_1) = 517.35$$



Linear Interpolation (contd)

$$L_0(t) = \prod_{\substack{j=0 \\ j \neq 0}}^1 \frac{t - t_j}{t_0 - t_j} = \frac{t - t_1}{t_0 - t_1}$$

$$L_1(t) = \prod_{\substack{j=0 \\ j \neq 1}}^1 \frac{t - t_j}{t_1 - t_j} = \frac{t - t_0}{t_1 - t_0}$$

$$v(t) = \frac{t - t_1}{t_0 - t_1} v(t_0) + \frac{t - t_0}{t_1 - t_0} v(t_1) = \frac{t - 20}{15 - 20} (362.78) + \frac{t - 15}{20 - 15} (517.35)$$

$$v(16) = \frac{16 - 20}{15 - 20} (362.78) + \frac{16 - 15}{20 - 15} (517.35)$$

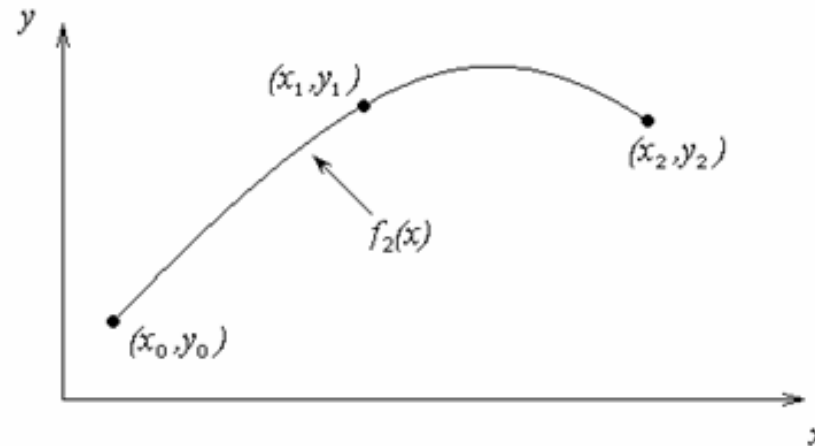
$$= 0.8(362.78) + 0.2(517.35)$$

$$= 393.7 \text{ m/s.}$$

Quadratic Interpolation

For the second order polynomial interpolation (also called quadratic interpolation), we choose the velocity given by

$$\begin{aligned}v(t) &= \sum_{i=0}^2 L_i(t)v(t_i) \\ &= L_0(t)v(t_0) + L_1(t)v(t_1) + L_2(t)v(t_2)\end{aligned}$$



Example

The upward velocity of a rocket is given as a function of time in Table 1. Find the velocity at $t=16$ seconds using the Lagrangian method for quadratic interpolation.

Table Velocity as a function of time

t (s)	$v(t)$ (m/s)
0	0
10	227.04
15	362.78
20	517.35
22.5	602.97
30	901.67

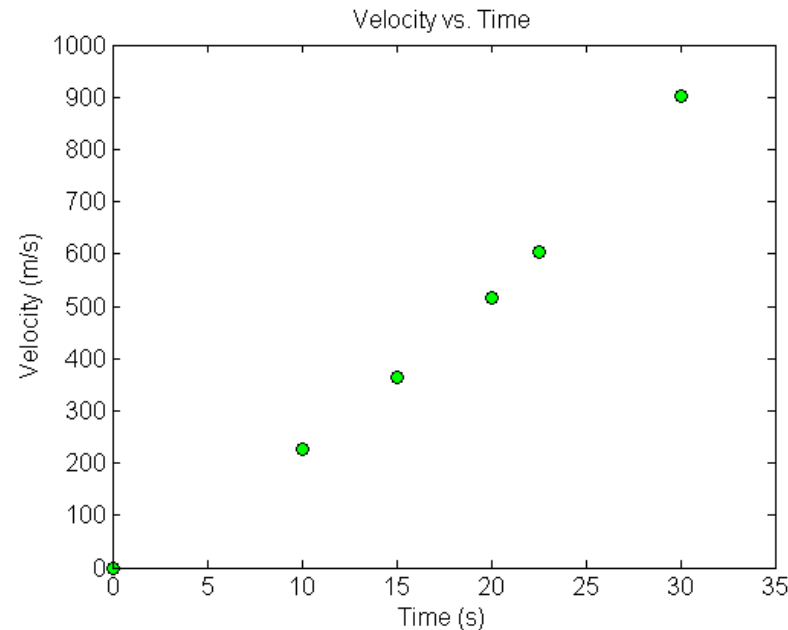


Figure. Velocity vs. time data
for the rocket example

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Quadratic Interpolation (contd)

$$t_0 = 10, v(t_0) = 227.04$$

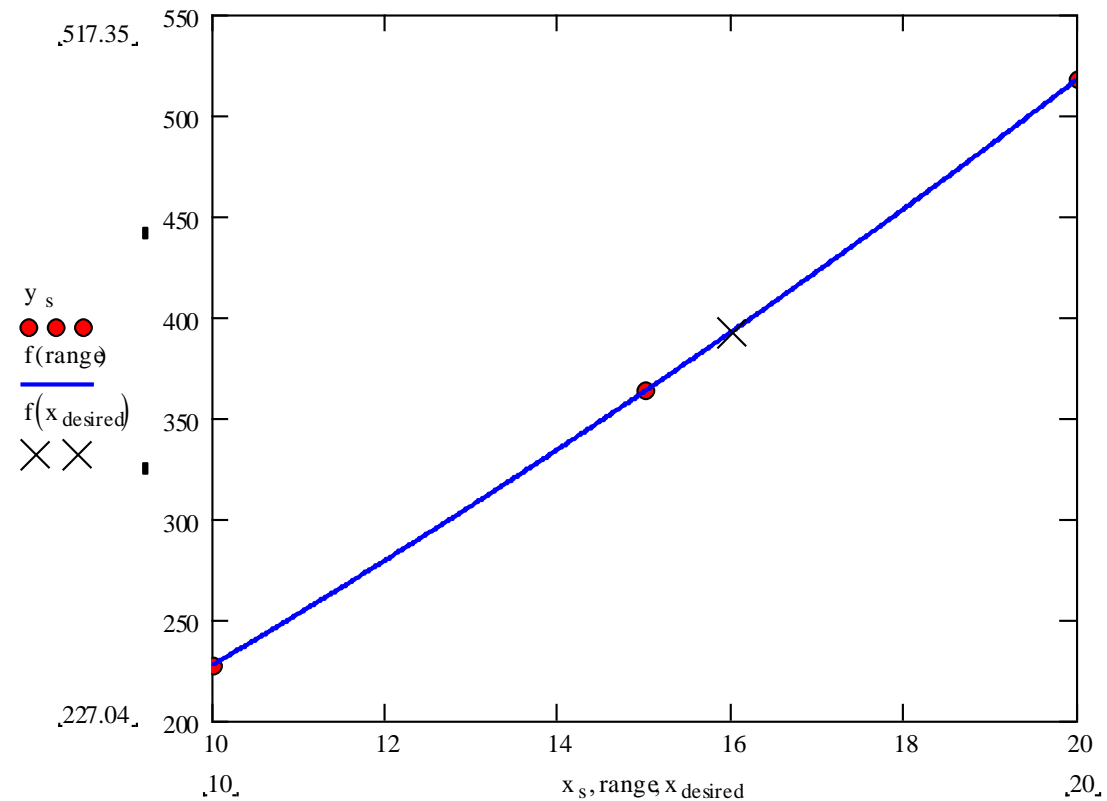
$$t_1 = 15, v(t_1) = 362.78$$

$$t_2 = 20, v(t_2) = 517.35$$

$$L_0(t) = \prod_{\substack{j=0 \\ j \neq 0}}^2 \frac{t - t_j}{t_0 - t_j} = \left(\frac{t - t_1}{t_0 - t_1} \right) \left(\frac{t - t_2}{t_0 - t_2} \right)$$

$$L_1(t) = \prod_{\substack{j=0 \\ j \neq 1}}^2 \frac{t - t_j}{t_1 - t_j} = \left(\frac{t - t_0}{t_1 - t_0} \right) \left(\frac{t - t_2}{t_1 - t_2} \right)$$

$$L_2(t) = \prod_{\substack{j=0 \\ j \neq 2}}^2 \frac{t - t_j}{t_2 - t_j} = \left(\frac{t - t_0}{t_2 - t_0} \right) \left(\frac{t - t_1}{t_2 - t_1} \right)$$



Quadratic Interpolation (contd)

$$\begin{aligned}v(t) &= \left(\frac{t-t_1}{t_0-t_1}\right)\left(\frac{t-t_2}{t_0-t_2}\right)v(t_0) + \left(\frac{t-t_0}{t_1-t_0}\right)\left(\frac{t-t_2}{t_1-t_2}\right)v(t_1) + \left(\frac{t-t_0}{t_2-t_0}\right)\left(\frac{t-t_1}{t_2-t_1}\right)v(t_2) \\v(16) &= \left(\frac{16-15}{10-15}\right)\left(\frac{16-20}{10-20}\right)(227.04) + \left(\frac{16-10}{15-10}\right)\left(\frac{16-20}{15-20}\right)(362.78) + \left(\frac{16-10}{20-10}\right)\left(\frac{16-15}{20-15}\right)(517.35) \\&= (-0.08)(227.04) + (0.96)(362.78) + (0.12)(527.35) \\&= 392.19 \text{ m/s}\end{aligned}$$

The absolute relative approximate error $|\epsilon_a|$ obtained between the results from the first and second order polynomial is

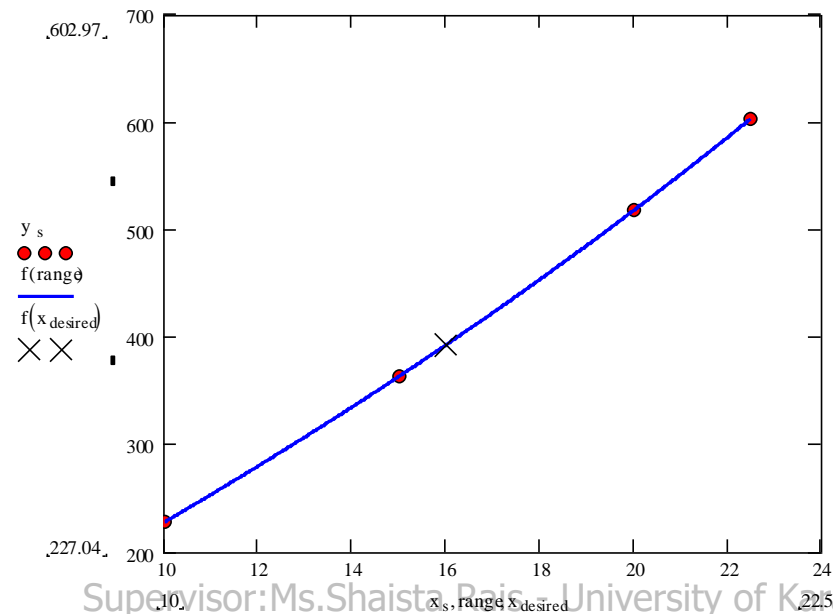
$$\begin{aligned}|\epsilon_a| &= \left| \frac{392.19 - 393.70}{392.19} \right| \times 100 \\&= 0.38410\%\end{aligned}$$

Cubic Interpolation

For the third order polynomial (also called cubic interpolation), we choose the velocity given by

$$v(t) = \sum_{i=0}^3 L_i(t)v(t_i)$$

$$= L_0(t)v(t_0) + L_1(t)v(t_1) + L_2(t)v(t_2) + L_3(t)v(t_3)$$



Example

The upward velocity of a rocket is given as a function of time in Table 1. Find the velocity at $t=16$ seconds using the Lagrangian method for cubic interpolation.

Table Velocity as a function of time

t (s)	$v(t)$ (m/s)
0	0
10	227.04
15	362.78
20	517.35
22.5	602.97
30	901.67

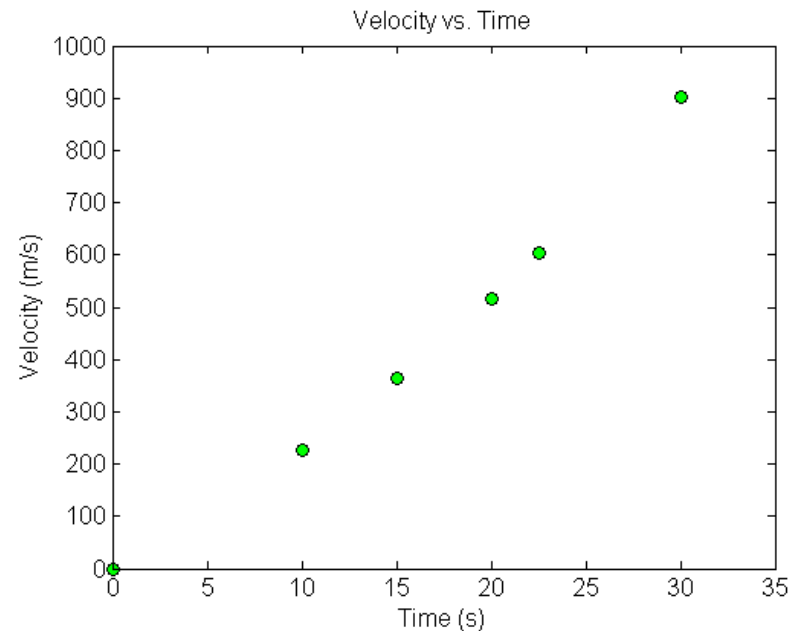


Figure. Velocity vs. time data
for the rocket example

Cubic Interpolation (contd)

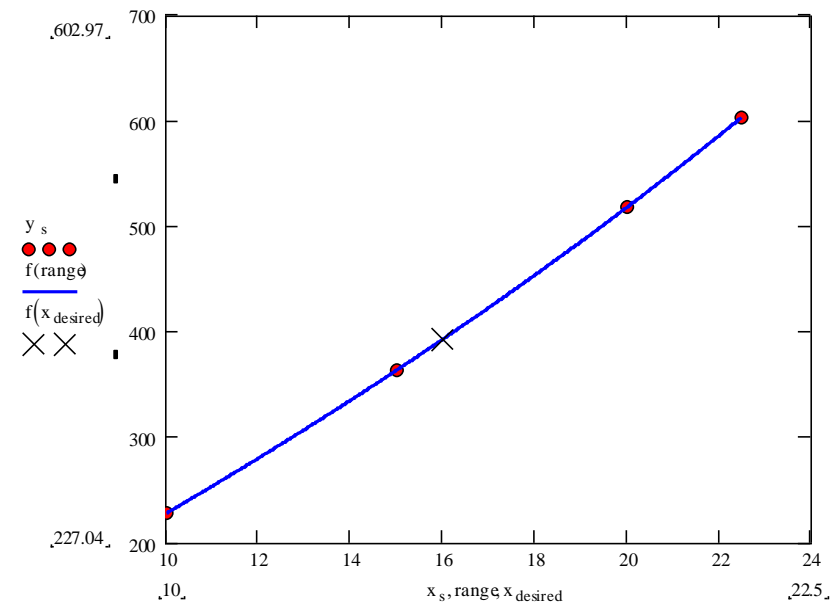
$$\begin{aligned} t_0 &= 10, \quad v(t_0) = 227.04 & t_1 &= 15, \quad v(t_1) = 362.78 \\ t_2 &= 20, \quad v(t_2) = 517.35 & t_3 &= 22.5, \quad v(t_3) = 602.97 \end{aligned}$$

$$L_0(t) = \prod_{\substack{j=0 \\ j \neq 0}}^3 \frac{t - t_j}{t_0 - t_j} = \left(\frac{t - t_1}{t_0 - t_1} \right) \left(\frac{t - t_2}{t_0 - t_2} \right) \left(\frac{t - t_3}{t_0 - t_3} \right);$$

$$L_1(t) = \prod_{\substack{j=0 \\ j \neq 1}}^3 \frac{t - t_j}{t_1 - t_j} = \left(\frac{t - t_0}{t_1 - t_0} \right) \left(\frac{t - t_2}{t_1 - t_2} \right) \left(\frac{t - t_3}{t_1 - t_3} \right)$$

$$L_2(t) = \prod_{\substack{j=0 \\ j \neq 2}}^3 \frac{t - t_j}{t_2 - t_j} = \left(\frac{t - t_0}{t_2 - t_0} \right) \left(\frac{t - t_1}{t_2 - t_1} \right) \left(\frac{t - t_3}{t_2 - t_3} \right);$$

$$L_3(t) = \prod_{\substack{j=0 \\ j \neq 3}}^3 \frac{t - t_j}{t_3 - t_j} = \left(\frac{t - t_0}{t_3 - t_0} \right) \left(\frac{t - t_1}{t_3 - t_1} \right) \left(\frac{t - t_2}{t_3 - t_2} \right)$$



Cubic Interpolation (contd)

$$\begin{aligned}
 v(t) &= \left(\frac{t-t_1}{t_0-t_1} \right) \left(\frac{t-t_2}{t_0-t_2} \right) \left(\frac{t-t_3}{t_0-t_3} \right) v(t_1) + \left(\frac{t-t_0}{t_1-t_0} \right) \left(\frac{t-t_2}{t_1-t_2} \right) \left(\frac{t-t_3}{t_1-t_3} \right) v(t_2) \\
 &\quad + \left(\frac{t-t_0}{t_2-t_0} \right) \left(\frac{t-t_1}{t_2-t_1} \right) \left(\frac{t-t_3}{t_2-t_3} \right) v(t_2) + \left(\frac{t-t_1}{t_3-t_1} \right) \left(\frac{t-t_0}{t_3-t_0} \right) \left(\frac{t-t_2}{t_3-t_2} \right) v(t_3) \\
 v(16) &= \left(\frac{16-15}{10-15} \right) \left(\frac{16-20}{10-20} \right) \left(\frac{16-22.5}{10-22.5} \right) (227.04) + \left(\frac{16-10}{15-10} \right) \left(\frac{16-20}{15-20} \right) \left(\frac{16-22.5}{15-22.5} \right) (362.78) \\
 &\quad + \left(\frac{16-10}{20-10} \right) \left(\frac{16-15}{20-15} \right) \left(\frac{16-22.5}{20-22.5} \right) (517.35) + \left(\frac{16-10}{22.5-10} \right) \left(\frac{16-15}{22.5-15} \right) \left(\frac{16-20}{22.5-20} \right) (602.97) \\
 &= (-0.0416)(227.04) + (0.832)(362.78) + (0.312)(517.35) + (-0.1024)(602.97) \\
 &= 392.06 \text{ m/s}
 \end{aligned}$$

The absolute relative approximate error $|\epsilon_a|$ obtained between the results from the first and second order polynomial is

$$\begin{aligned}
 |\epsilon| &= \left| \frac{392.06 - 392.19}{392.06} \right| \times 100 \\
 &= 0.033269\%
 \end{aligned}$$

Comparison Table

Order of Polynomial	1	2	3
$v(t=16)$ m/s	393.69	392.19	392.06
Absolute Relative Approximate Error	-----	0.38410%	0.033269%